Supporting citizen inquiry: an investigation of Moon rock

Conference or Workshop Item

Supporting Citizen Inquiry: an investigation of Moon Rock

Eloy Villasclaras-Fernandez[1], Mike Sharples[1], Simon Kelley[2], Eileen Scanlon[1]

[1]Institute of Educational Technology, The Open University, UK
[2]Faculty of Science, The Open University, UK

(eloy.villasclaras-fernandez, mike.sharples, e.scanlon, s.p.kelley)@open.ac.uk

Abstract. Citizen inquiry is an innovative way for non-professionals to engage in practical scientific activities, in which they take the role of self-regulated scientists in informal learning contexts. This type of activity has similarities to inquiry-based learning and to citizen science, but also important differences. To understand the challenges of supporting citizen inquiry, a prototype system and activity has been developed: the *Moon Rock Explorer*. Based on the *nQuire* Toolkit, this offers people without geology expertise an open investigation into authentic specimens of Moon rock, using a *Virtual Microscope*. The *Moon Rock Explorer* inquiry has been evaluated in an informal learning context with PhD students from the Open University. Results of the evaluation raise issues related to motivation and interaction between inquiry participants. They also provide evidence that the integration of scientific tools was successful and that the *nQuire* Toolkit is suitable to deploy and enact citizen inquiries.

1 Introduction

There is a growing interest in involving non-professionals and learners in scientific activities. For example, Alberts (2011), in an editorial for the Science, argues that wider personal engagement in "carefully designed, hands-on, inquiry-based exploration of the world" (p. 1604) will inform public debate and may lead to scientific breakthroughs. A central challenge is how to enable widespread involvement in this scientific inquiry process, such that large scale online collaboration can be combined with inquiry based learning. We aim to address this challenge by developing **citizen inquiry** as a new theory and practice of informal education.

The aim of citizen inquiry is to create a novel synthesis of **citizen science** and **inquiry-based learning**. Since the early 20th century, citizen science projects have enabled non-professionals to participate in real scientific investigations, more recently through online activity. *Galaxy Zoo* (Raddick et al., 2007) relies on volunteers doing analysis of astronomy images. In the *Great Sunflower Project* [http://www.greatsunflower.org/] members of the public can contribute to study bee populations by cultivating plants in their own gardens. For *Fold it* people engage in

adfa, p. 1, 2011.

creative game-like activities to propose new protein geometry (Cooper et al., 2010). The motivation for citizen science projects comes typically from the need for large amount of computer power (e.g., *Seti@Home*, *Rosetta@Home*) or intelligent effort, as in the aforementioned projects. As a by-product, citizen science allows people to become members of the scientific community and contribute towards the development of innovative science. It may also enable members of the public to learn about topics of their interest or gain understanding of scientific methods, but supporting productive learning is not integral to citizen science.

Inquiry-based learning (IBL) also has a long pedigree. From the early 20th century onwards (Dewey, 1910) there have been proposals that children should learn science through collaborative inquiry. Since scientific thinking is essentially social, Dewey proposed that schools should become "laboratories of knowledge-making" (Dewey, 1910, p. 127) where children engage in experimentation, communication, and self-criticism, constituting a youthful commonwealth of cooperative inquiry. Yorks & Kasl (2002) have shown how scientific inquiry can be applied successfully in adult learning, as a systematic and productive process for learning from personal experience, consisting of repeated episodes of reflection and action through which a group of peers strives to answer a question of mutual importance. The inquiry-based learning process of proposing and conducting experiments, collecting data, and engaging in self-criticism based on one's own data, can have positive effects on the understanding of content material and the scientific method (White & Frederiksen, 1998).

To date, most inquiry-based learning activities have been conducted with pupils in the classroom, mediated by a teacher. Recent research has devised a new process of curriculum-based inquiry that extends beyond the classroom, supported by a personal inquiry toolkit implemented on a mobile device. In this approach, children typically start a science investigation in the classroom managed by a teacher, then continue it at home or outside with the aid of the mobile toolkit, then share, discuss, and present their findings back in the classroom (Anastopoulou et al., 2012). This has shown success in engaging children with scientific activity, in teaching science topics, and in maintaining enjoyment of science lessons. But there is no evidence that children come to identify more strongly with science and scientists as a result of engaging with school-managed personal inquiry activities, nor of increased leisure interest or personal engagement with science outside school.

2 Citizen inquiry

The term 'citizen inquiry' refers to the design and enactment of scientific projects by non-professional scientists in supportive communities, combining the benefits of large scale participation in authentic science practices with inquiry into scientific topics of personal interest and value. Our aim is to design and deploy an infrastructure that enables members of the public to develop their scientific interest in an innovative manner, in which they become independent scientists and investigate questions and hypotheses of their own or shared interest.

Citizen inquiry integrates methods from personal inquiry learning, citizen science, and open science (Woelfle, et al., 2011). It shares with citizen science an open nature, being driven by personal interest and developed outside of formal education. Compared to different models of citizen science (Wilderman, 2007), citizen inquiry is closer to participatory action research; however the goal is not to involve members of the public in professional scientific projects. Rather, it focuses on empowering members of the public to employ scientific tools and methods, augmenting their autonomy to plan and conduct scientific investigations not necessarily managed by professionals. It could be undertaken in at home or outdoors, by children or adults, providing there is opportunity to enact a complete inquiry cycle, a rich physical or social environment to investigate, a community of engaged peers, and a set of tools to guide the process and collect data. These requirements present challenges of theory and practice:

- *Motivating participants*. Citizen science projects attract the interest of volunteers by their high profile, such as the search for extra-terrestrial life, or their contribution to science by addressing important medical or environmental problems. Conversely, students engaged in IBL activities are typically guided by their teachers, with extrinsic motivation provided by the curriculum and examining. We need to investigate whether an activity without these external influences will attract and maintain the interest of participants. In citizen inquiry, the initial motivation comes from personal interest in a topic, which is then maintained by forming or joining a club of investigators with similar interests and a diversity of contexts.
- *Devising scientific activities*. Devising a scientific question is a challenging task. While citizen inquiries may be developed out of curiosity without need for wider relevancy, we are interested in the possibilities for non-professionals to make valid contributions to science. This may not be the 'big science' of medical advances or scientific breakthroughs, but it should be personally relevant to the participants and also have a wider meaning and validity, adopting methods recognised by the scientific community. Investigations into supernatural, metaphysical or pseudo-scientific phenomena may not enable citizens to access scientific literature, learn how to use complex tools, understand scientific theories, or adhere to the ethical principles of the scientific community.
- *Managing inquiry processes*. Citizen science relies on professional scientists to plan investigations with suitable methodologies, whereas IBL activities are managed by some combination of teacher and students. Some give responsibility to the learners to plan their experiments; others encourage learners to decide the research questions that will be investigated. A goal of citizen inquiry is to offer learners the opportunity to propose and design their investigations. However, it is challenging to devise investigations that are personally engaging, testable by available tools, and sufficiently constrained to allow collection and analysis of data (Anastopoulou et al., 2012). Typically, learners have problems managing their process of inquiry. They need specific support in designing appropriate experiments (e.g. what variables to choose, how to state and test hypotheses), implementing experiments (e.g. making predictions and avoiding being fixated with achieving particular results ra-

ther than testing hypotheses), and interpreting results (e.g. explaining graphs) (van Joolingen et al., 2005; Quintana et al., 2004). The teacher has an essential role to provide guidance and to ensure appropriate quality of questions and methods planned by the students (Sharples & Anastopoulou, 2011). It is unclear whether non-scientists in *ad hoc* teams can plan or adopt inquiry processes that follow the good practices of professional science.

Within the IBL field, these issues are being tackled by the development of computer systems that provide support to learners, guiding them through a structured process of devising a topic, deciding a research question, planning a method, collecting and analysing data, answering the research question, sharing findings and reflecting on progress (Linn, Clark & Slotta, 2002). Following the same approach, we have developed a citizen inquiry support system, built on the *nQuire* inquiry learning platform, to manage the process of open participation in science inquiry and to study the role of technology in addressing the aforementioned challenges.

In addition to devising and testing software to support citizen inquiry, we are interested in understanding the management of online scientific communities. Online collaborative forums have been deployed to support inquiry learning (Linn & Slotta, 2006) and are widely used in citizen science (Bonney et al., 2009). The *iSpot* platform has a reputation management system (Clow & Makriyannis, 2011), enabling users to have their developing expertise recognized within the community. The *Fold it* user community provides a novel form of community engagement through protein folding competitions (Cooper, et al., 2010). Strong user communities would be needed to support motivation and learning in citizen inquiry if neither teachers nor science experts were available to guide the scientific process.

Our interest in citizen inquiry arises from its potential as a mechanism for informal learning, to facilitate comprehension of science in the everyday world, and the scientific methodology behind it. Specifically, the research presented in this paper is focused on how citizen inquiry activities can be supported through online systems and the building of online communities of users with shared interests. The next section describes the development the *nQuire* inquiry support system, already openly available, to support online investigation of lunar rocks: the *Moon Rock Explorer*. Section 4 describes the design of a study to evaluate this inquiry, which was conducted during February 2013. Section 5 discusses the results, and lastly, Section 6 presents the conclusions and future steps.

3 Development of a citizen inquiry activity

Following the challenges listed above, this section describes a citizen inquiry on the subject of Moon Geology. Rather than developing a new software system, we have adapted *nQuire*, an existing tool for IBL.

3.1 Inquiry Based Learning support

The *Personal Inquiry* project developed the *nQuire* toolkit to support IBL activities for science learning in secondary education (Mulholland et al., 2012). The toolkit runs on laptop or tablet computers and enables teachers set up investigations that can be conducted within and outside the classroom. Investigations developed for the Personal Inquiry project covered the themes of Myself (activity and heart rate; healthy eating), My Environment (effect of noise pollution on bird feeding; microclimates; urban heat islands), and My Community (food packaging and decay).

A distinctive feature of *nQuire* compared to other IBL tools (such as *SCY* and *Let's Go*) is its representation of an entire investigation (Scanlon, et al., 2011).

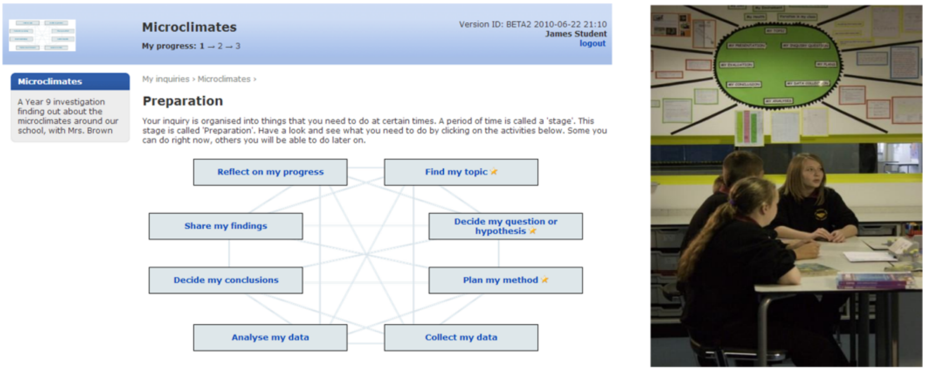

Fig. 1. Representation of the inquiry cycle (a) on the *nQuire* screen, (b) on the classroom wall

As shown in Figure 1(a), *nQuire* depicts an investigation as a cyclical sequence of activities. This is shown as an interactive diagram on the *nQuire* home screen and is also used by the teachers to organise the sequence of activities: one teacher produced a version of the diagram as a large poster on the classroom wall Figure 1(b). It shows the activities as interconnected, indicating that although students are expected to progress round the inquiry cycle, they may also start at any phase and revisit earlier phases, for example to revise the inquiry question so that it matches the methods.

Current development of *nQuire* is being continued through its integration into the *OpenScience Laboratory* (OSL) (http://www8.open.ac.uk/choose/ou/openscience), a project funded by The Open University and the Wolfson Foundation. The OSL is an online hub to access virtual instruments and practical science experiments. It integrates virtual and remote scientific tools, such as a field trip in a virtual world and control of remote telescope, accessible through web browsers. All the data provided by the real or virtual equipment is authentic, not simulated, gained from remotely-operated sensors, photo-realistic recordings of physical experiments and microscope images of real specimens. The OSL enables students on courses in higher education to conduct practical science experiments and some of the experiments will be open to the general public.

By integrating *nQuire*, the OSL will assist students and members of the public to engage in investigations that access sophisticated tools. This opens new possibilities for investigating IBL with *nQuire*, extending it from secondary education to undergraduate courses. It also represents an opportunity to investigate citizen inquiry.

3.2 The *Moon Rock Explorer* citizen inquiry

The *Moon Rock Explorer* is prototype demonstrator and test-site of citizen inquiry. It provides a self-managed investigation into Moon geology for people with no previous knowledge of Moon rock or geology. A user accesses the system through a public URL (www.*nQuire*.info/*nQuire*) and is presented with a video introduction to moon rock and an appeal to 'Investigate Moon Rock'. Having created an account, the user is taken to the home page, similar to that shown in Figure 1(a), but with six phases: Introduction, Decide my question, Plan my method, Collect my data, Analyse my data, Decide my conclusions. Entering at the Introduction phase, the user is shown photographs of four samples collected by Apollo astronauts – two of basalt Moon rock and two of Moon dust, or regolith – and is set the challenge to identify the differences between them.

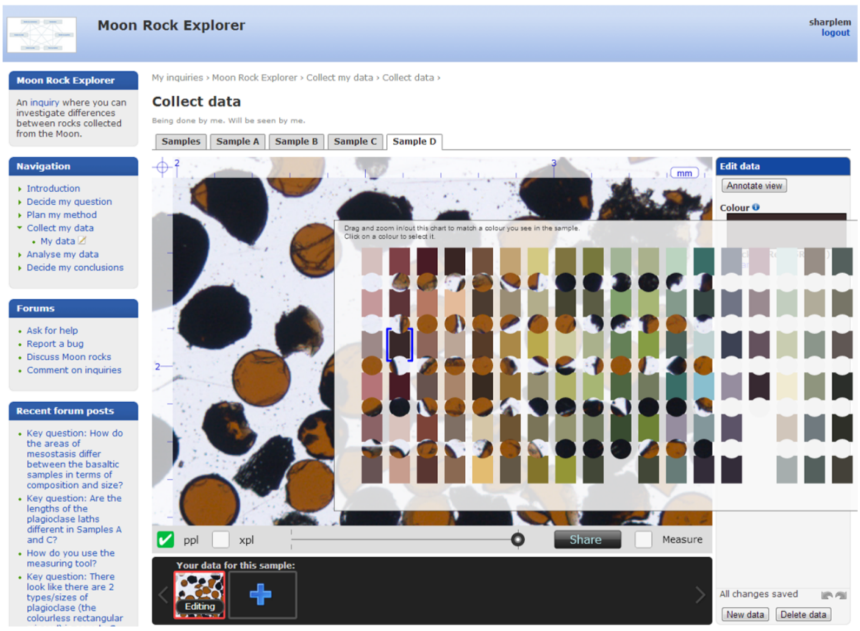

Fig. 2. *Moon Rock Explorer* inquiry, showing the *Virtual Microscope* tool and colour chart ('Drag and zoom this chart in and out to match a colour in the sample. Click on a colour to select it.').

3.3 User experience of the *Moon Rock Explorer*

Typically, a user will first examine the four rock samples under a '*Virtual Microscope*' which allows study of digitised thin rock sections (0.03mm polished slices), with the ability to increase the magnification, zoom into an area of a slice and view in both plane-polarised and cross-polarised light. Then, the user will propose one or more specific questions to investigate, such as ‘why are some grains in sample D bright orange?’ or ‘is there a difference in the average grain size between the four samples?’ The questions need not be confined to the microscope, and the *Moon Rock Explorer* provides links to lunar maps and NASA sites giving background information on the Apollo missions. The next phase is to plan a method of investigation, which for the microscope involves selecting the measures from: grain size, distance, colour, opacity and crystal shape. The microscope provides tools to make these measurements for each sample. Having collected data, the user may move to analysing the data by creating a graph for selected measures (see Figure 3). Lastly, the user can propose answers to the questions based on a personal interpretation of the measures and plots, then post an automatically-compiled set of findings on the public forum.

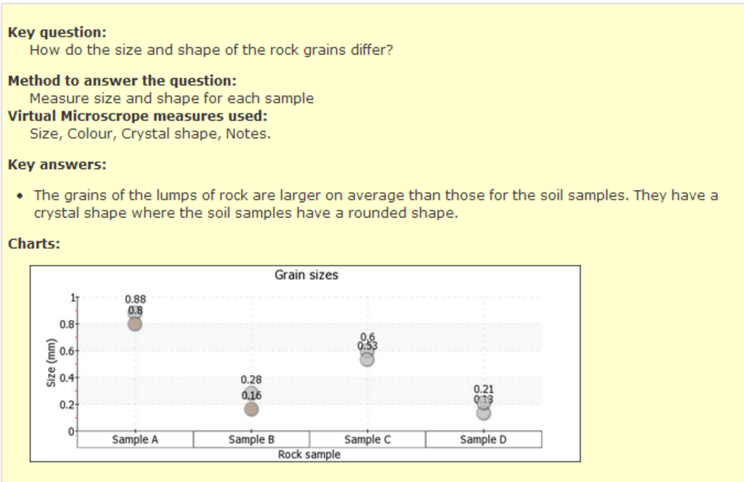

Fig. 3. Summary of an inquiry compiled by the *Moon Rock Explorer*

Although the *Moon Rock Explorer* is implemented on a version of the *nQuire* platform used for the Personal Inquiry project, it differs in three main aspects that are intended to support self-directed citizen inquiry rather than teacher-led inquiry:

1. **Simplified representation of the inquiry cycle**. The inquiry cycle was adapted for self-managed learning by adults, by reducing the number of phases (e.g., ‘Reflect on my progress’ was removed) and amending the informational text in each phase, accounting to take account of the fact that no teacher is present. Temporal restrictions on access to different phases of the inquiry were eliminated: the user can always access and re-visit any phase of the inquiry.
2. **Integration of scientific tools.** The *Moon Rock Explorer* was integrated with the Open University *Virtual Microscope* to promote scientifically relevant inquiries and learner motivation. Access to real Moon rock samples is extremely limited, so

students and members of the public would not normally be able to examine them in detail. The microscope includes a measure tool, which lets users collect accurate data on grain size and separation, and a colour chart (Figure 2), based on a Rock-Color Chart produced by the Geological Society of America, to identify colours in the sample. Data collected with these tools is automatically recorded in *nQuire*.

3. **Addition of an online community system.** Although each investigation can be carried out autonomously, users can use the forum to interact with others. In addition, when an inquiry summary is generated by the system, there is a button to 'publish this question and discuss it with other users'. If a user chooses to do so, the system will create automatically a new forum thread to show with the investigation summary (see Figure 3). Changes to the research question, the research method, data, or answers, will also be updated in the forum thread. These threads can be used for discussion or even for peer-review between users.

3.4 Development of the *Moon Rock Explorer*

The *Moon Rock Explorer* was developed through a rapid iterative cycle of design, implementation and testing, initially involving members of the team, then with expert usability testers conducting heuristic evaluations (Nielsen & Molich, 1990). The heuristic evaluation helped us to improve the user interface, especially to enable users to collect large amounts of data easily using the *Virtual Microscope*.

4 Evaluation

The development of the *Moon Rock Explorer* inquiry allows us to investigate the challenges of citizen inquiry activities. To that purpose, we have conducted a study using the *Moon Rock Explorer* inquiry in an informal learning setting. The goals of the study are to determine the relevance of the challenges discussed in Section 2 and assess the support implemented in the *Moon Rock Explorer* inquiry to overcome them:

- **Issue 1: Motivation**. Is the inquiry topic interesting for the target audience? Are the features of the inquiry appropriate to maintain participants' motivation? Do users support each other in their personal inquiries?
- **Issue 2: Management of inquiry processes**. Can participants develop complete inquiries following the inquiry cycle adapted from IBL activities? Is the guidance provided by the system sufficient?
- **Issue 3: Relevant scientific activities**. Are the questions proposed by the participants scientifically relevant? Does the integrated *Virtual Microscope* allow the participants to collect data for their investigations?

4.1 Method

The study follows loosely a Design Based Research approach (Wang & Hannafin, 2005), involving PhD students in from the Faculty of Sciences of the Open University. To frame the study in an informal learning context, their participation was voluntary and the study was connected to their doctoral work. Moreover, the staff responsible for the study did not provide any guidance as in teacher-led activities. The study had the following structure:

1. They are invited to participate through email, including an activity schedule.
2. A one-hour face-to-face briefing session introduces them to the *Moon Rock Explorer*. Participants are encouraged to join, complete an inquiry, or just visit the forum.
3. The *Moon Rock Explorer* website is open for two weeks. Users can register and access any part of the system. Two academics from the Faculty of Science join the inquiry in the role of 'expert geologists', and monitor the forum for questions. Except for indicating that we will accept participation within a two-week period, there are no scheduled tasks, and the participants are free to register and complete the activities in their own time.
4. Online survey. A brief questionnaire about their perception of the experience.
5. Focus group. Participants are invited to a one-hour focus group, two weeks after the completion of Phase 3.

4.2 Sample

Participants were recruited from the collective of PhD students in the Faculty of Sciences at the Open University; their PhD studies are mostly related to astronomy, geology and planetary science. Therefore, the original participant pool included students who were interested in science and had with differing levels of expertise in general geology and the geology of the Moon.

Six students eventually registered in the system and carried out (completely or partially) the inquiry. While the number of participants is lower than initially expected, it reflects the voluntary nature of the inquiry and the study.

4.3 Data analysis

The goals of the study are focused on understanding the challenges of supporting this type of inquiry, rather than on observing gains on students' domain knowledge, scientific skills or attitudes towards science. The study was designed according to a mixed method that combines qualitative and quantitative data (Cairns & Cox, 2008). Both types of data are combined to reveal tendencies related to participants' activity and their interaction with the system and between themselves.

Qualitative data includes: participants' profile, answers to the online questionnaires (identified as *[OQ]* in the rest of the paper), answers in the focus group (*[FG]*), and contributions to the forum (*[F]*). Quantitative data is obtained from *nQuire* logs, which include the amount of user-created content and page visits; these refer to both inquiry-related content and forum contributions

5 Results

This section details the results obtained from the evaluation described in Section 4. The analysis of the data is presented here in relation to the issues discussed throughout the paper.

5.1 Motivation

Motivation and entry barrier

The first question concerning motivation, as indicated in Section 4, was: "**Is the inquiry topic interesting for the target audience?**" In the case of the *Moon Rock Explorer* inquiry, the target users are novice geologists. However, five out of six participants were had previous expertise in geology (see Table 1). Only one student without previous experience in geology joined the inquiry, and this participant created a significantly lower amount of inquiry content. Against our expectation, the 'expert participants' were more interested in the inquiry than providing help to other users (see 'motivation and user interaction' below). Therefore, the results lead us to believe that the *Moon Rock Explorer* has a high entry barrier and was more motivating for participants with prior knowledge in geology than novices.

Table 1. Participants prior knowledge (*E*: doing research on geology; *L*: different background, but limited experience in geology; *N*: no previous experience) and inquiry-related content.

Experience	Key questions	Data	Data charts	Key answers
E	1	35	1	0
E	1	32	1	0
E	1	0 (used external software)		1
E	2 (1 investigated)	15	0	0
L	3 (1 investigated)	40	3	1
N	1	0	0	0

Motivation and inquiry design

To answer the question "**Are the features of the inquiry appropriate to maintain participants' motivation?**" we consider two different issues.

First, the Moon Rock Inquiry was designed as an open-ended inquiry without fixed research questions. While this may have contributed to the high entry barrier, it was suitable for participants with prior knowledge of geology. This is supported by the comments in the final questionnaire (e.g.: "*I liked being able to explore the four samples with the virtual microscope […]*" [OQ]), the quality of the questions they proposed, and by the amount of data they collected to answer their questions (see Table 1), amounting to two hours work in the case of one participant [FG].

A second issue goes beyond the selected domain of inquiry. Some participants did not answer any questions, even after collecting data for them (Table 1). Asked about this, the participants found that there was a lack of purpose in the inquiry [FG]. Indeed, the only product of their activity that could be shared with other users was the automatic forum investigation summaries, which had problems discussed below.

Motivation and user interaction

The objective of investigating interactions between users was obviously affected by the low number of participants. Users could interact through the forum, even though the inquiry activities were individual. We have identified and characterized a number of interaction types.

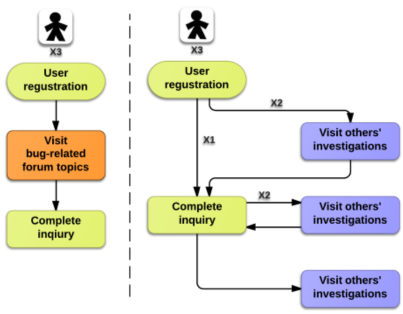

Fig. 4. Patterns of interaction through investigation visits. Number of participants is indicated

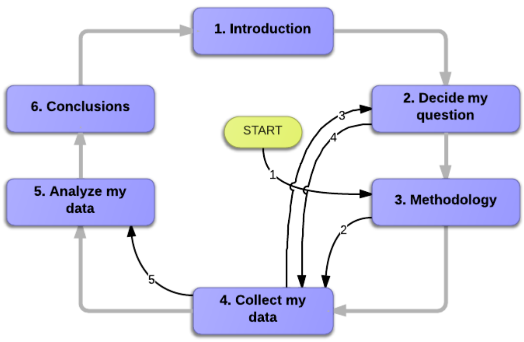

Fig. 5. Alternative participant learning flow. Grey lines represent the suggested path; black lines the alternative path.

1. The first type of interaction is related to participants **discussing the investigations of others in the forum**. Unfortunately, no participants commented on other investigations, which was an unexpected result. They reported that they did not feel comfortable to do so, because they did not know the state of each investigation, and were concerned about intruding [FG].
2. Participants did, however, **visit other investigations**. This happened 31 times. Log analysis allows us to identify two patterns in this behaviour, as shown in Figure 4. The first pattern (Figure 4-left) was carried out by three participants with previous expertise in Geology. They did not look at other investigations, even though they visited forum topics related to bugs and the tool. The second pattern (Figure 4-right) was followed by three participants with varying levels of expertise. Again, this was against our expectation, as we had expected interest from the experts to see other participants' work and help, if possible.
3. Related to this, a third type of interaction involves **asking domain related questions** and obtaining answers from knowledgeable members of the community. This

happened only once [F]. The question was answered by a member of staff, and the rest of the participants did not intervene in the discussion.

4. A final form of interaction consists of **asking non-domain questions**. This was limited to bug reports made in the forum, which were answered by the administrator after the problems had been fixed [F].

Unfortunately, the results indicate that the system did not encourage participants to interact with each other. The available data indicates thus a negative answer to the questions: "**Does the system support the creation of a user community?**" And "**Do users support each other in their personal inquiries?**"

5.2 Management of inquiry processes

The management of inquiry processes had been evaluated thoroughly using *nQuire* in teacher-led inquiries. In contrast, in our study the role of a teacher or tutor was not present, so we were concerned about a potential lack of support.

The analysis of the participants' work indicates however that the participants could complete the whole activity, leading to positive comments such as: "*I also liked the way that each part of the investigation led on to the next,*" [OQ]. Thus, we answer positively to the questions "**Can participants develop complete inquiries following the inquiry cycle adapted from IBL activities?**" And: "**Is the guidance provided by the system sufficient?**"

Besides the support provided to guide participants across the proposed inquiry process, we are interested in their own processes. The *nQuire* Toolkit was designed to allow participants to follow different paths, visiting the activities in their order (the Network representation in Figure 1). However, the log analysis shows that nearly all the participants progressed in the order suggested by the Navigation element of the *nQuire* user interface (left panel in Figure 2). The only case of an alternative process is shown in Figure 5. This participant started by collecting data, in order to familiarize herself with the tool, then moved to propose a key question. Participants noted contrasts between the Network and linear Navigation representations and were confused by the differences [FG]. It is important to understand whether the *nQuire* interface discourages alternative progressions, and the potential risks of this issue.

5.3 Relevant scientific activities

Regarding the last issue, we were interested in whether "**the integrated *Virtual Microscope* allow the participants collect data or their investigations**" The amount of data collected by the participants (Table 1) confirms that they were capable of collecting a large number of measures using the *Virtual Microscope*. Qualitative data confirms this, e.g.: "*comparing the four slides quickly and easily - more easily, in fact, than would be possible with a real microscope!*" [OQ]

The study revealed, on the other hand, technical problems. First, the participants reported that after a number of data had been collected, it become difficult to remember which features of a specimen had been measured [FG][OQ]. A second problem is the lack of a powerful data analysis tool: one participant collected her data using external spreadsheet software that allowed more sophisticated analysis [F]. Despite these problems, we consider that the evaluation of the *nQuire*/*Virtual Microscope* integration is positive, as it satisfied its goal: to provide a tool to collect scientifically reliable data which can be used to answer research investigations.

6 Conclusions and future directions

The development and evaluation of the *Moon Rock Explorer* inquiry is the first step towards understanding the requirements of citizen inquiry. The long term goals of this research are to support learners in adopting an inquiry-based learning approach in a self-regulated and self-directed context, and to support the creation of citizen inquiry user communities. A milestone in this research is the integration of *nQuire* with the scientific instruments of the OSL, which will enable users to create inquiries for a wide range of scientific domains.

The study presented in this paper provides initial evidence of the suitability of *nQuire* and the *Virtual Microscope* to support citizen inquiry activities, notwithstanding some problems with the current implementation that need to be addressed. A key result of the study is the successful guidance provided by *nQuire*. The tool is currently being extended with an inquiry authoring tool. Feedback from the study is being used to refine the *nQuire-Virtual Microscope* user interface.

The most exciting open challenges are related to the issue of motivation. Several mechanisms are under consideration to foster motivation in collaborative inquiries: reputation systems (as in *iSpot*), support for roles within large scale inquiries (similar to citizen science projects), and an internal peer-reviewed 'scientific journal' for members of the citizen inquiry community. Further research is needed to understand these and other mechanisms in the context of citizen inquiry.

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